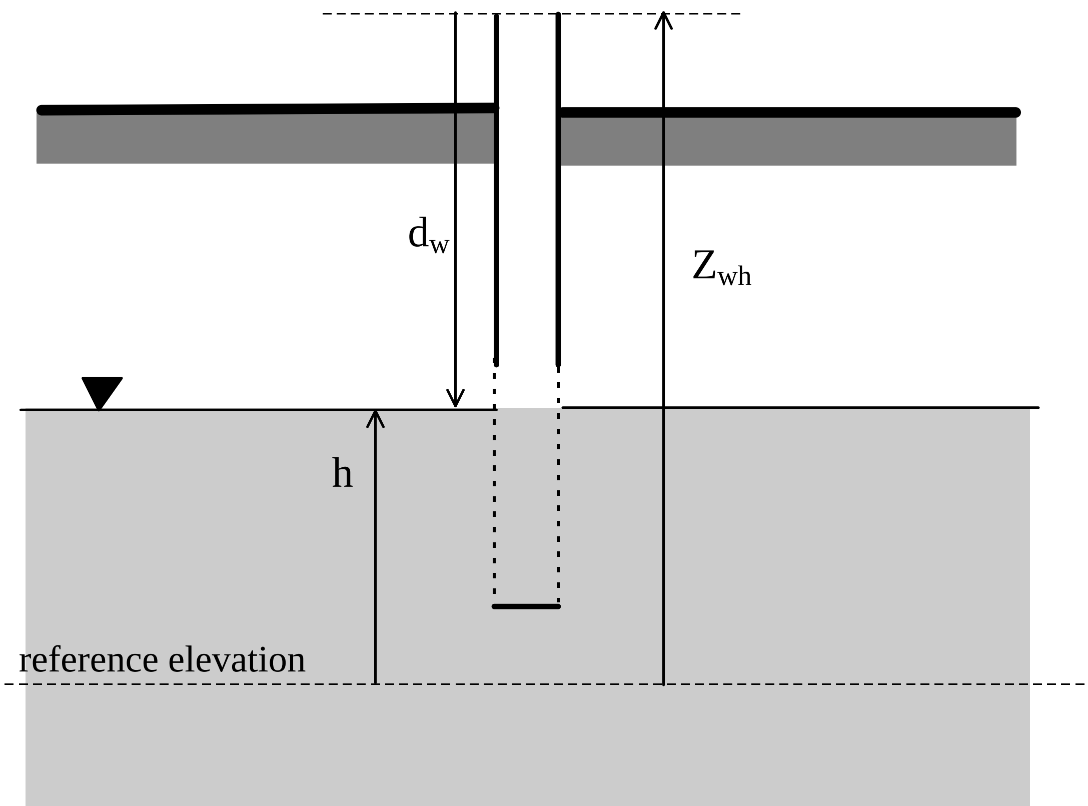
FLOW NETS (AH: Chapter 5.11):

- Map showing lines of equal head and direction of flow.

1. MEASURING HYDRAULIC HEAD:



Head = Elevation at well head - depth to water

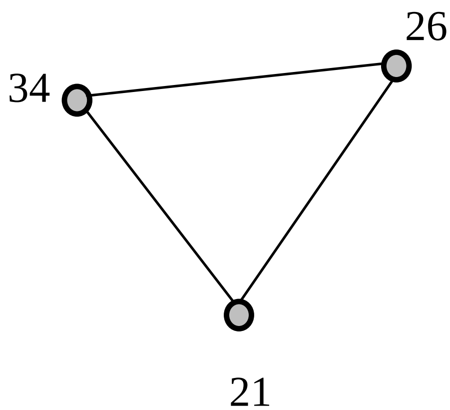
Important Considerations:

1. Screened interval of well (same aquifer? vertical gradients?)

2. Time (transient conditions [e.g., recharge], tidal effects, atmospheric pressure effects) - see fig 4.10, 4.11

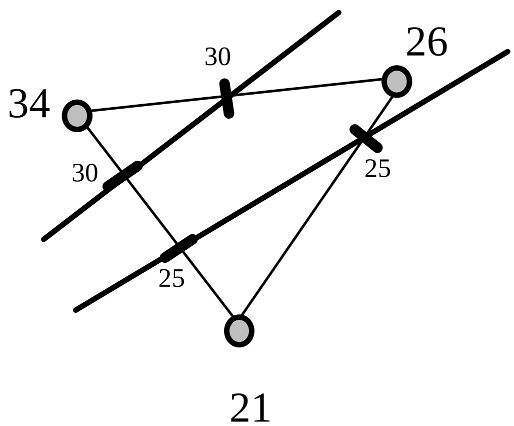
3. Surveyed location of well (x,y,z).

2. MAPPING EQUIPOTENTIAL LINES IN A HORIZONTAL PLANE.



3 locations in a horizontal plane:
- *wells or piezometers*
- *nodes from numerical model*

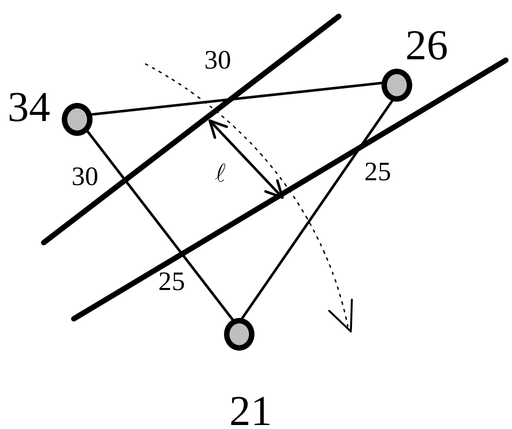
All represent head at a location in the same aquifer--no vertical gradients.



Connect all points with lines.

Interpolate head values between points.

Construct lines of equal head:
- *Pieziometric Surface*
- *Potentiometric Surface*
- *Water table elevation (surface aquifer only)*

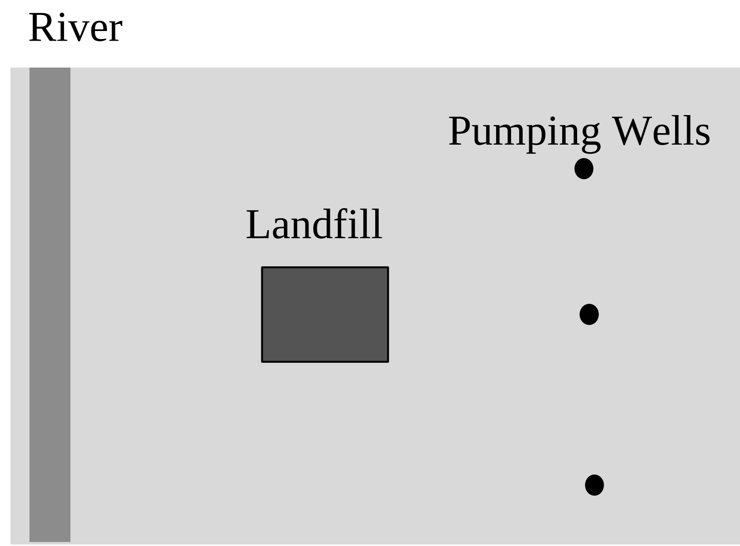


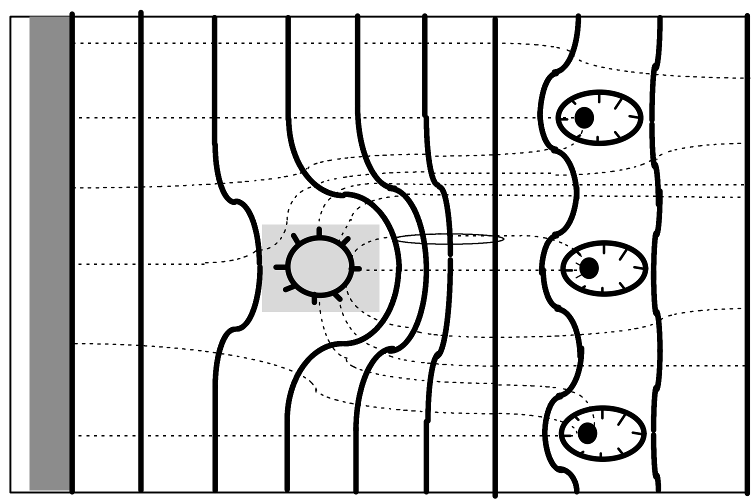
Construct flow lines crossing perpendicular to equipotential lines.

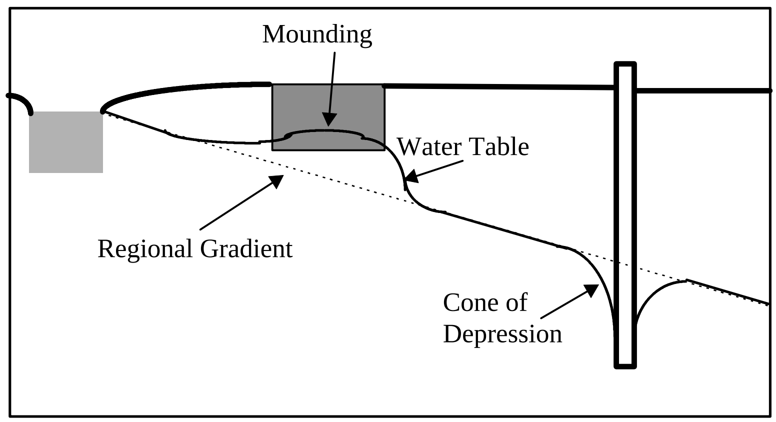
Calculate gradient along flow line, $(h_2 - h_1)/\ell$.

Apply Darcy Equation to calculate velocity.

FLOW NETS: Continued:







Observe patterns in flow net:

1. Equipotential lines closer together = steeper gradient
   = increasing flow rate?
   = decreasing hydraulic conductivity?

2. Flow lines: Converging = increasing flow rate
   Diverging = decreasing flow rate

   Demonstrate velocity vectors
   Demonstrate solute transport path

Δ Storage Term

Affected by 3 variables which may change with TIME:
Note: $z \neq f(t)$

1. Water Density
   Compressible Fluid, $\rho = f(P) = g(h)$
   Incompressible Fluid, ρ = constant

2. Porosity
   Deformable Media, $n = f(P) = g(h)$
   Nondeformable Media, n = constant

3. Saturation
   Unsaturated, $S = f(P) = g(h)$
   Saturated, $S = 1$

Δ Storage Term

8 possible combinations - We will discuss 3:

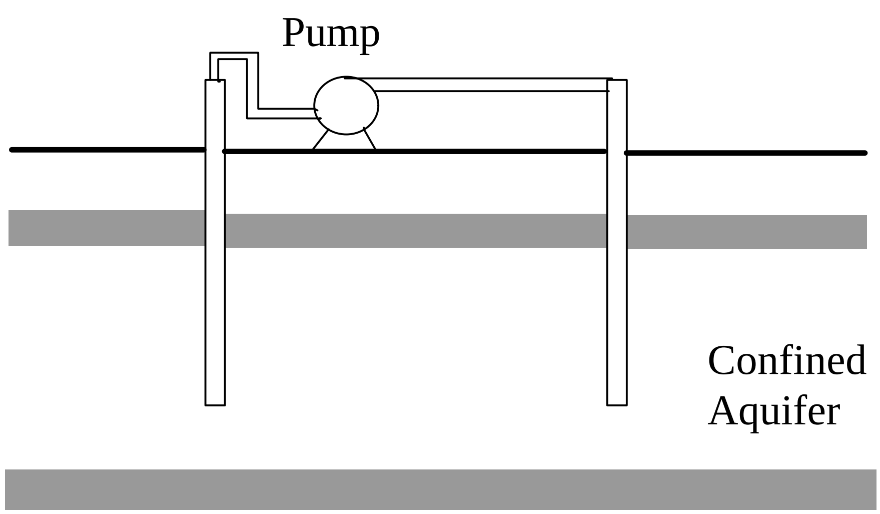
CONDITION 1: Incompressible fluid, nondeformable media, saturated conditions:

$$\frac{\partial}{\partial t}(\rho\theta) = 0$$

Condition required for steady state.

Does it guarantee steady state?

What is steady state?



Δ Storage = 0 does not mean that flow rates, flow directions, and hydraulic heads cannot change with time.

Δ Storage Term, Continued:

CONDITION 2: Compressible fluid, deformable media, saturated conditions:

Specific Storage Relationship

$$\frac{\partial}{\partial t}(\rho n) = \rho S_s \frac{\partial h}{\partial t}$$

Consider: Confined aquifer under pressure. Relieve pressure by pumping:

1. Water expands slightly; density decreases.
2. Soil grains "settle" or compress; porosity decreases.

Effects are combined in specific storage, S_s, (L^{-1})

$$S_s = \frac{\text{Vol. } H_2O \text{ released from storage}}{(\text{Vol. Aquifer})(\text{Unit decline in head})}$$

Typical value ≈ 10^{-6} ft^{-1}

Note: density is assumed not be a function of space, and drops from the mass balance equation.

Insert in Flow Balance Equation:

Heterogeneous/Anisotropic:

$$S_s \frac{\partial h}{\partial t} = \frac{\partial}{\partial x} K_x \frac{\partial h}{\partial x} + \frac{\partial}{\partial y} K_y \frac{\partial h}{\partial y} + \frac{\partial}{\partial z} K_z \frac{\partial h}{\partial z}$$

Homogeneous/Isotropic:

$$\frac{S_s}{K}\frac{\partial h}{\partial t} = \frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}$$

CONDITION 3: Incompressible Fluid, Nondeformable Medium, Unsaturated Conditions.

To be covered in Unsaturated flow unit.

BOUNDARY CONDITIONS:

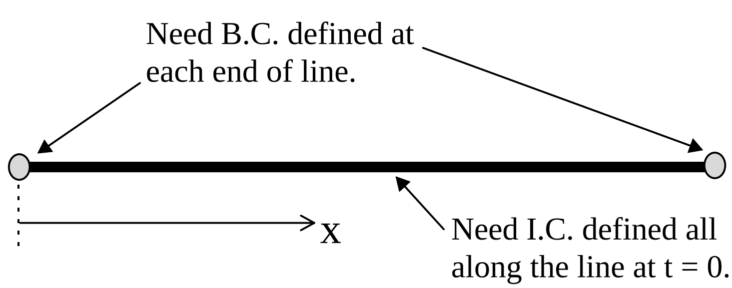
Mass balance equation lets us develop the GOVERNING EQUATIONS for flow in porous media.

To model the system (i.e., solve the equations), we need to know the boundary conditions:

1. *Boundary conditions in space*:
   Needed for both transient and steady state solutions.

2. *Boundary conditions in time (a.k.a. initial conditions):*
   Needed for transient solutions.

1-D Problem:



BOUNDARY CONDITIONS:

2-D Problem:

TYPES OF BOUNDARY CONDITIONS:

- Flow equations are solved it terms of head, h
- Boundary conditions must be defined in terms of head.

1. Constant head boundary: $h(x=0, y, t) = 20$ ft.

Examples:
- Surface water (river, lake) with "constant" elevation
- Regional groundwater elevation at a location beyond influence of local effects (e.g., pumping)

2. Constant flux boundary: $\left.\dfrac{\partial h}{\partial y}\right|_{(x, y=0, t)} = 0$

Constant gradient = constant flow rate
zero gradient = no flow

Examples:
- Boundary parallel to mean flow direction beyond range of local effects.

3. Initial Conditions: $h(x,y,t=0) = f(x,y)$

- Can use steady state solution for flow conditions prior to application of stresses which cause transient conditions.

Questions:

Are boundary/initial conditions reasonable assumptions?

Do the boundary conditions remain reasonable throughout the simulation?